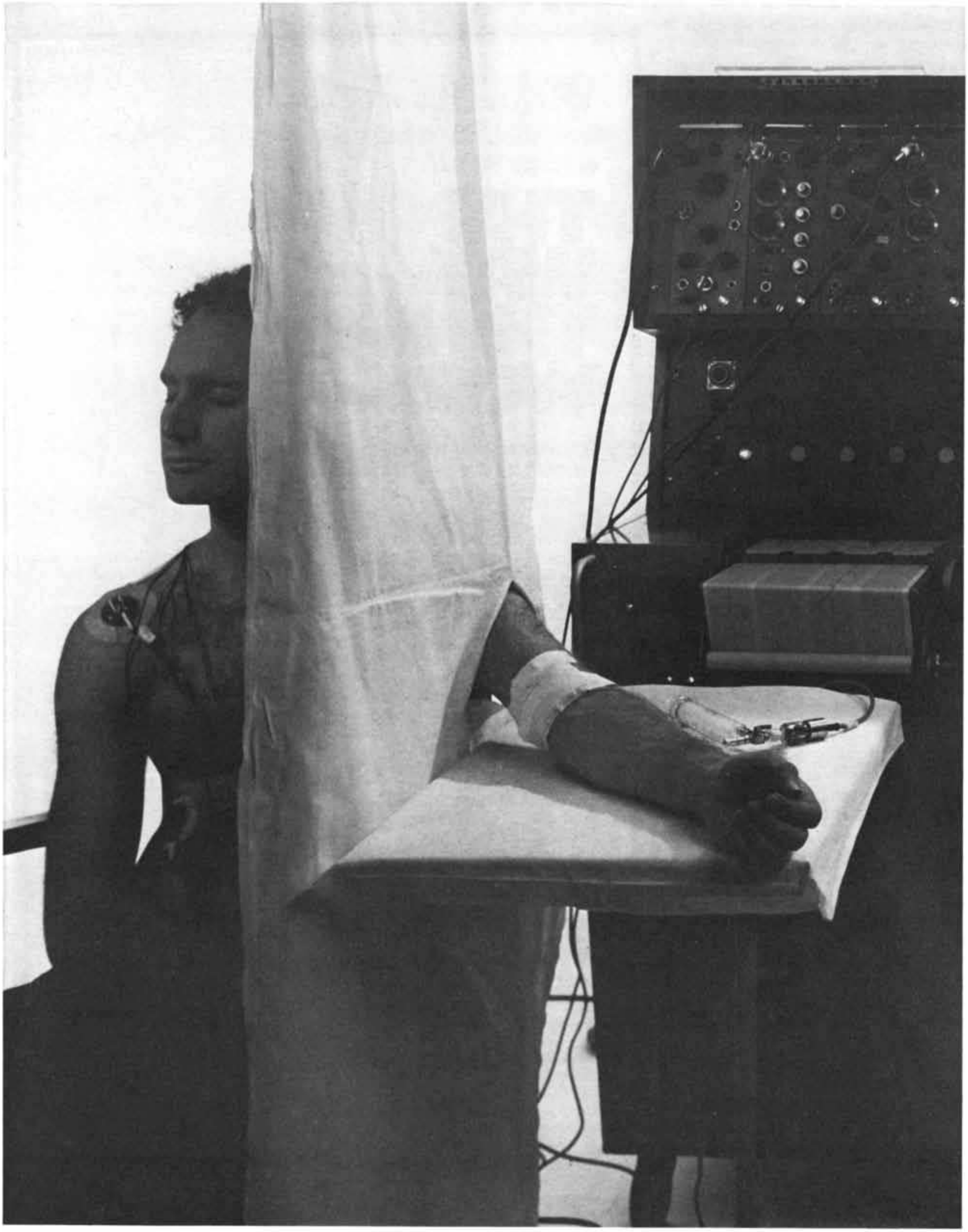


ISOLATED SUBJECT is connected with an instrument array that continuously records such physiological variables as heart rate and blood pressure. A catheter in the subject's left arm draws samples of arterial blood at 10-minute intervals; these samples are analyzed for oxygen and carbon dioxide content and for blood acidity and blood-lactate level. The subject's arm is screened from his view to minimize the psychological effects of blood withdrawal. Each subject first sat quietly for an interval and then was invited to meditate for a 30-minute period. At the end of the period the subject was asked to stop meditating but to continue sitting quietly during a further recording interval. Thirty-six qualified "transcendental" meditators from 17 to 41 years old volunteered as subjects for the study, which was conducted both at the Harvard Medical Unit of the Boston City Hospital and at the University of California at Irvine.

THE PHYSIOLOGY OF MEDITATION

Is the meditative state that is achieved by yogis and other Far Eastern mystics accompanied by distinct physiological changes? A study of volunteer subjects in the U.S. indicates that it is

by Robert Keith Wallace and Herbert Benson

How capable is the human organism of adjusting to psychologically disturbing changes in the environment? Our technological age is probably testing this capacity more severely than it was ever tested in the past. The impact of the rapid changes—unprecedented in scale, complexity and novelty—that technology is bringing about in our world seems to be having a deleterious effect on the mental and physical health of modern man. Some of the common disorders of our age, notably "nervous stomach" and high blood pressure, may well be attributable in part to the uncertainties that are burgeoning in our environment and daily lives. Since the environment is not likely to grow less complex or more predictable, it seems only prudent to devote some investigative attention to the human body's resources for coping with the vicissitudes of the environment.

There are in fact several ways in which an individual can control his physiological reactions to psychological events. Among the claims for such control the most notable have come from practitioners of meditation systems of the East: yoga and Zen Buddhism. This article will review and discuss recent studies of the effects of meditation that have been made by ourselves and by other investigators.

Yogis in India have long been reputed to perform phenomenal feats such as voluntarily stopping the heartbeat or surviving for extended periods in an "airtight" pit or in extreme cold without food or in a distorted physical posture. One of the first investigators to look into these claims in an objective way was a French cardiologist, Thérèse Brosse, who went to India in 1935 equipped with a portable electrocardiograph so that she could monitor the activity of the heart. Brosse concluded from her tests that one of her subjects actually was able to stop his heart. In 1957 two American physiologists, M. A. Wenger of the University of California at Los Angeles and B. K. Bagchi of the University of Michigan Medical School, conducted a more extensive investigation in collaboration with B. K. Anand of the All-India Institute of Medical Sciences in New Delhi. None of the yogis they studied, with more elaborate equipment than Brosse had used, showed a capability for stopping the heart. Wenger and Bagchi concluded that the disappearance of the signal of heart activity in Brosse's electrocardiogram was probably an artifact, since the heart impulse is sometimes obscured by electrical signals from contracting muscles of the thorax. (In attempting to stop the heart the yogis usually performed what is called the Valsalva maneuver, which increases the pressure within the chest; it can be done by holding one's breath and straining downward.) Wenger, Bagchi and Anand did find, however, that some of the yogis could slow both heartbeat and respiration rate.

Reports of a number of other investigations by researchers in the 1950's and 1960's indicated that meditation as practiced by yoga or Zen meditators could produce a variety of physiological effects. One of the demonstrated effects was reduction of the rate of metabolism. Examining Zen monks in Japan who had had many years of experience in the practice of deep meditation, Y. Sugi and K. Akutsu found that during meditation the subjects decreased their consumption of oxygen by about 20 percent and reduced their output of carbon dioxide. These signs of course constitute evidence of a slowing of metabolism. In New Delhi, Anand and two collaborators, G. S. Chhina and Baldeu Singh, made a similar finding in examination of a yoga practitioner; confined in a sealed metal box, the meditating yogi markedly reduced his oxygen consumption and carbon dioxide elimination.

These tests strongly indicated that meditation produced the effects through control of an "involuntary" mechanism in the body, presumably the autonomic nervous system. The reduction of carbon dioxide elimination might have been accounted for by a recognizably voluntary action of the subject—slowing the breathing—but such action should not markedly affect the uptake of oxygen by the body tissues. Consequently it was a reasonable supposition that the drop in oxygen consumption, reflecting a decrease in the need for inhaled oxygen, must be due to modification of a process not subject to manipulation in the usual sense.

Explorations with the electroencephalograph showed further that meditation produced changes in the electrical activity of the brain. In studies of Zen monks A. Kasamatsu and T. Hirai of the University of Tokyo found that during meditation with their eyes half-open the monks developed a predominance of alpha waves—the waves that ordinarily become prominent when a person is thoroughly relaxed with his eyes closed. In the meditating monks the alpha waves increased in amplitude and regularity, particularly in the frontal and central regions of the brain. Subjects with a great deal of experience in meditation showed other changes: the alpha waves slowed from the usual frequency of nine to 12 cycles per second to seven or eight cycles per second, and rhythmical theta waves at six to seven cycles per second appeared. Anand and other investigators in India found that yogis, like the Zen monks, also showed a heightening of alpha activity during meditation. N. N. Das and H. Gastaut, in an electroencephalographic examination of seven yogis,

observed that as the meditation progressed the alpha waves gave way to fast-wave activity at the rate of 40 to 45 cycles per second and these waves in turn subsided with a return of the slow alpha and theta waves.

Another physiological response tested by the early investigators was the resistance of the skin to an electric current. This measure is thought by some to reflect the level of "anxiety": a decrease in skin resistance representing greater anxiety; a rise in resistance, greater relaxation. It turns out that meditation increases the skin resistance in yogis and somewhat stabilizes the resistance in Zen meditators.

We decided to undertake a systematic study of the physiological "effects," or, as we prefer to say, the physiological correlates, of meditation. In our review of the literature we had found a bewildering range of variation in the cases and the results of the different studies. The subjects varied greatly in their meditation techniques, their expertise and their performance. This was not so true of the Zen practitioners, all of whom employ the same technique, but it was quite characteristic of the practice of yoga, which has many more adherents. The state called yoga (meaning "union") has a generally agreed definition: a "higher" consciousness achieved through a fully rested and relaxed body and a fully awake and relaxed mind. In the endeavor to arrive at this state, however, the practitioners in India use a variety of approaches. Some seek the goal through strenuous physical exercise; others concentrate on controlling a particular overt function, such as the respiratory rate; others focus on purely mental processes, based on some device for concentration or contemplation. The difference in technique may produce a dichotomy of physiological effects; for instance, whereas those who use contemplation show a decrease in oxygen consumption, those who use physical exercise to achieve yoga show an oxygen-consumption increase. Moreover, since most of the techniques require rigorous discipline and long training, the range in abilities is wide, and it is difficult to know who is an "expert" or how expert he may be. Obviously all these complications made the problem of selecting suitable subjects for our systematic study a formidable one.

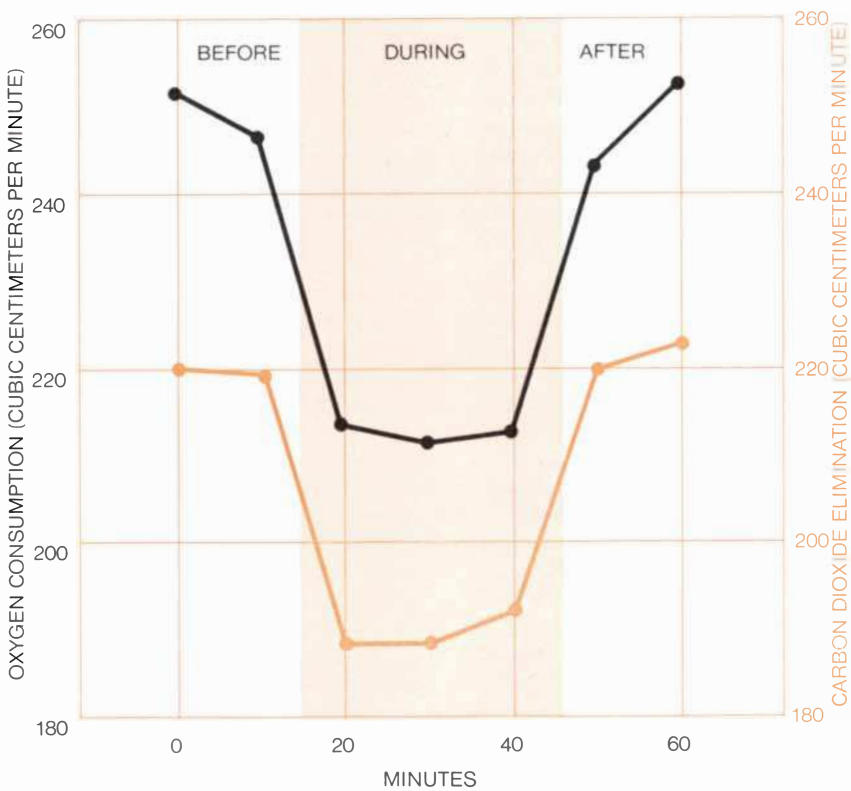
Fortunately one widely practiced yoga technique is so well standardized that it enabled us to carry out large-scale studies under reasonably uniform conditions. This technique, called "transcendental meditation," was developed by Maharishi Mahesh Yogi and is taught by an organization of instructors whom he personally qualifies. The technique does not require intense concentration or any form of rigorous mental or physical control, and it is easily learned, so that all subjects who have been through a relatively short period of training are "experts." The training does not involve devotion to any specific beliefs or life-style. It consists simply in two daily sessions of practice, each for 15 to 20 minutes.

The practitioner sits in a comfortable position with eyes closed. By a systematic method that he has been taught, he perceives a "suitable" sound or thought. Without attempting to concentrate specifically on this cue, he allows his mind to experience it freely, and his thinking, as the practitioners themselves report, rises to a "finer and more creative level in an easy and natural manner." More than 90,000 men and women in the U.S. are said to have received instruction in transcendental meditation by the organization teaching it. Hence large numbers of uniformly trained subjects were available for our studies.

What follows is a report of the detailed measurements made on a group of 36 subjects. Some were observed at the Thorndike Memorial Laboratory, a part of the Harvard Medical Unit at the Boston City Hospital. The others were observed at the University of California at Irvine. Twenty-eight were males and eight were females; they ranged in age from 17 to 41. Their experience in meditation ranged from less than a month to nine years, with the majority having had two to three years of experience.

During each test the subject served as his own control, spending part of the session in meditation and part in a normal, nonmeditative state. Devices for continuous measurement of blood pressure, heart rate, rectal temperature, skin resistance and electroencephalographic events were attached to the subject, and during the period of measurement samples were taken at 10-minute intervals for analysis of oxygen consumption, carbon dioxide elimination and other parameters. The subject sat in a chair. After a 30-minute period of habituation, measurements were started and continued for three periods: 20 to 30 minutes of a quiet, premeditative state, then 20 to 30 minutes of meditation, and finally 20 to 30 minutes after the subject was asked to stop meditating.

The measurements of oxygen consumption and carbon dioxide elimination confirmed in precise detail what had



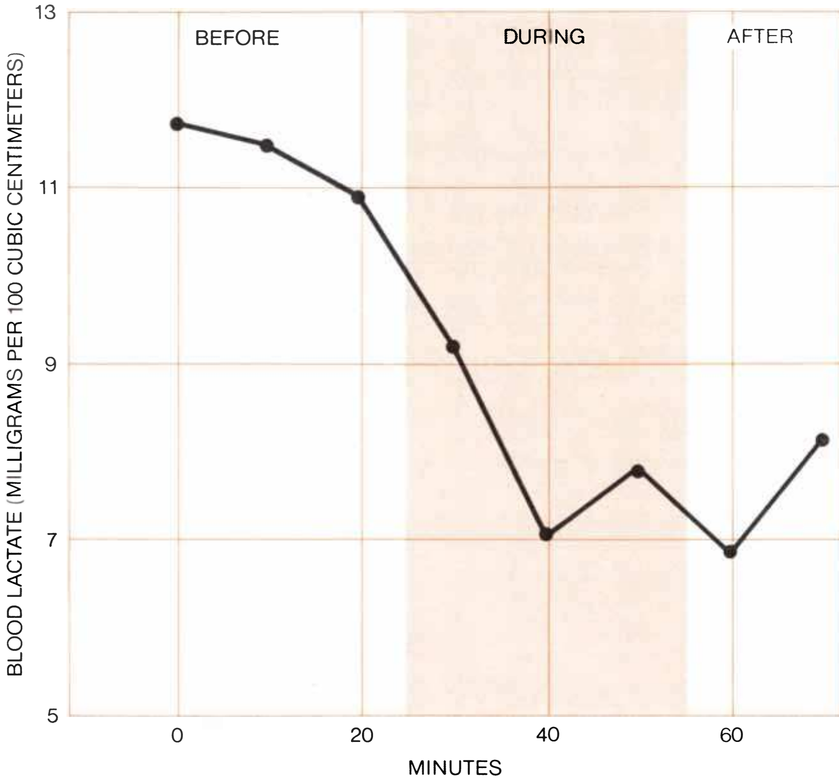
EFFECT OF MEDITATION on the subjects' oxygen consumption (*black*) and carbon dioxide elimination (*color*) was recorded in 20 and 15 cases respectively. After the subjects were invited to meditate both rates decreased markedly (*colored area*). Consumption and elimination returned to the premeditation level soon after the subjects stopped meditating.

been reported earlier. Oxygen consumption fell sharply from 251 cubic centimeters per minute in the premeditation period to 211 cubic centimeters during meditation, and in the postmeditation period it rose gradually to 242 cubic centimeters. Similarly, carbon dioxide elimination decreased, from 219 centimeters per minute beforehand to 187 cubic centimeters during meditation, and then returned to about the premeditation level afterward. The ratio of carbon dioxide elimination to oxygen consumption (in volume) remained essentially unchanged throughout the three periods, which indicates that the controlling factor for both was the rate of metabolism. The reduction in metabolic rate (and hence in the need for oxygen) during meditation was reflected in a decrease, essentially involuntary, in the rate of respiration (off two breaths per minute) and in the volume of air breathed (one liter less per minute).

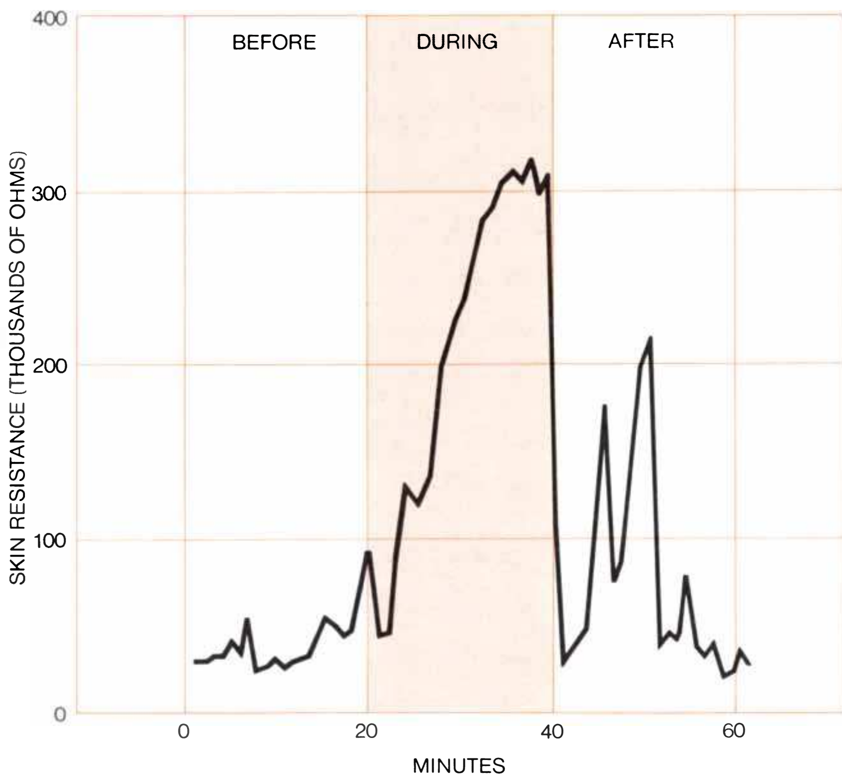
For the measurement of arterial blood pressure and the taking of blood samples we used a catheter, which was inserted in the brachial artery and hidden with a curtain so that the subject would not be exposed to possible psychological trauma from witnessing the drawing of blood. Since local anesthesia was used at the site of the catheter insertion in the forearm, the subject felt no sensation when blood samples were taken. The blood pressure was measured continuously by means of a measuring device connected to the catheter.

We found that the subjects' arterial blood pressure remained at a rather low level throughout the examination; it fell to this level during the quiet premeditation period and did not change significantly during meditation or afterward. On the average the systolic pressure was equal to 106 millimeters of mercury, the diastolic pressure to 57 and the mean pressure to 75. The partial pressures of carbon dioxide and oxygen in the arterial blood also remained essentially unchanged during meditation. There was a slight increase in the acidity of the blood, indicating a slight metabolic acidosis, during meditation, but the acidity was within the normal range of variation.

Measurements of the lactate concentration in the blood (an indication of anaerobic metabolism, or metabolism in the absence of free oxygen) showed that during meditation the subjects' lactate level declined precipitously. During the first 10 minutes of meditation the lactate level in the subjects' arterial blood decreased at the rate of 10.26 milligrams per 100 cubic centimeters per hour, nearly four times faster than the rate of



RAPID DECLINE in the concentration of blood lactate is apparent following the invitation to start meditating (*colored area*). Lactate is produced by anaerobic metabolism, mainly in muscle tissue. Its concentration normally falls in a subject at rest, but the rate of decline during meditation proved to be more than three times faster than the normal rate.



RAPID RISE in the electrical resistance of the skin accompanied meditation (*colored area*) in a representative subject. The 15 subjects tested showed a rise of about 140,000 ohms in 20 minutes. In sleep skin resistance normally rises but not so much or at such a rate.

decrease in people normally resting in a supine position or in the subjects themselves during their premeditation period. After the subjects ceased meditating the lactate level continued to fall for a few minutes and then began to rise, but at the end of the postmeditation period it was still considerably below the premeditation level. The mean level during the premeditation period was 11.4 milligrams per 100 cubic centimeters, during meditation 8.0 milligrams and during postmeditation 7.3 milligrams.

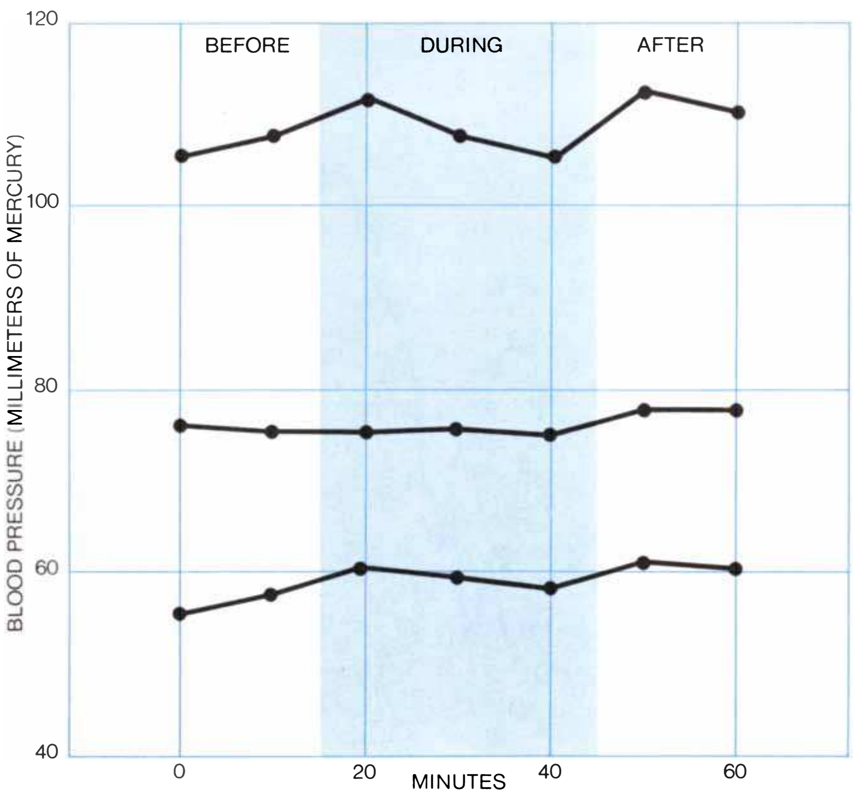
How could one account for the fact that lactate production, which reflects anaerobic metabolism, was reduced so much during meditation? New experiments furnished a possible answer. These had to do with the rate of blood flow in meditating subjects; the explanation they suggest appears significant with respect to the psychological benefits that can be obtained from meditation.

In studies H. Rieckert conducted at the University of Tübingen, he reported that during transcendental meditation his subjects showed a 300 percent increase in the flow of blood in the forearm. In similar measurements on our subjects we found the increase in forearm blood flow to be much less: 32 percent. Still, this increase was interesting, and it offered an explanation of the relatively large decrease in blood-lactate concentration. The main site of lactate production in the body is the skeletal muscle tissue. Presumably the observed acceleration of blood flow to the forearm muscles during meditation speeds up the delivery of oxygen to the muscles. The resulting gain in oxidative metabolism may substitute for anaerobic metabolism, and this would explain the sharp drop in the production of lactate that accompanies meditation.

The intriguing consequence of this view is that it brings the autonomic nervous system further into the picture. In a situation of constant blood pressure (which is the case during meditation) the rate of blood flow is controlled basically by dilation or constriction of the blood vessels. The autonomic nervous system, in turn, controls this blood-vessel behavior. One element in this system, a part of the sympathetic nerve network, sometimes gives rise to the secretion of acetylcholine through special fibers and thereby stimulates the blood vessels to dilate. Conversely, the major part of the sympathetic nerve network stimulates the secretion of norepinephrine and thus causes constriction of the blood vessels. Rieckert's finding of a large increase in blood flow during meditation suggested that meditation increased the activity of the sympathetic nerve network that secretes the dilating substance. Our own finding of a much more modest enhancement of blood flow indicated a different view: that meditation reduces the activity of the major part of the sympathetic nerve network, so that its constriction of the blood vessels is absent. This interpretation also helps to account for the great decrease in the production of lactate during meditation; norepinephrine is known to stimulate lactate production, and a reduction in the secretion of norepinephrine, through inhibition of the major sympathetic network, should be expected to diminish the output of lactate.

Whatever the explanation of the fall in the blood-lactate level, it is clear that this could have a beneficial psychological effect. Patients with anxiety neurosis show a large rise in blood lactate when they are placed under stress [see "The Biochemistry of Anxiety," by Ferris N. Pitts, Jr.; SCIENTIFIC AMERICAN, February, 1969]. Indeed, Pitts and J. N. McClure, Jr., a co-worker of Pitts's at the Washington University School of Medicine, showed experimentally that an infusion of lactate could bring on attacks of anxiety in such patients and could even produce anxiety symptoms in normal subjects. Furthermore, it is significant that patients with hypertension (essential and renal) show higher blood-lactate levels in a resting state than patients without hypertension, whereas in contrast the low lactate level in transcendental meditators is associated with low blood pressure. All in all, it is reasonable to hypothesize that the low level of lactate found in subjects during and after transcendental meditation may be responsible in part for the meditators' thoroughly relaxed state.

Other measurements on the meditators confirmed the picture of a highly relaxed, although wakeful, condition. During meditation their skin resistance to an electric current increased markedly, in some cases more than fourfold. Their heart rate slowed by about three beats per minute on the average. Electroencephalographic recordings disclosed a marked intensification of alpha waves in all the subjects. We recorded the waves from seven main areas of the brain on magnetic tape and then analyzed the patterns with a computer. Typically there was an increase in intensity of slow alpha waves at eight or nine cycles per second in the frontal and central regions of the brain during meditation. In several subjects this change was also accompanied by prominent theta waves in the frontal area.

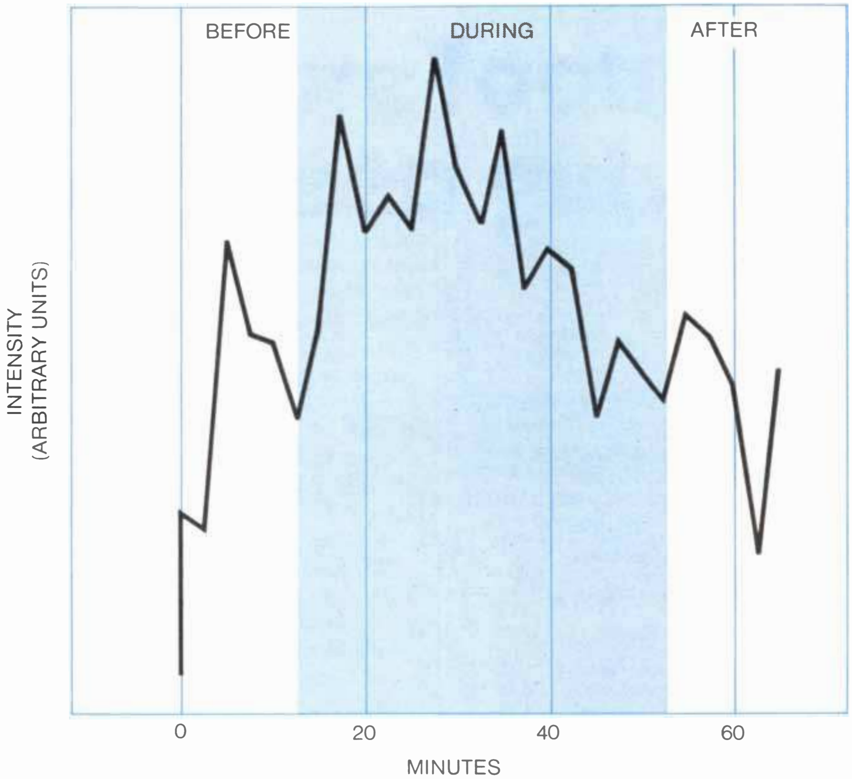


NO SIGNIFICANT CHANGE was observed in nine subjects whose arterial blood pressure was recorded before, during and after meditation. Systolic pressure (*top*), mean pressure (*middle*) and diastolic pressure (*bottom*), however, stayed relatively low throughout.

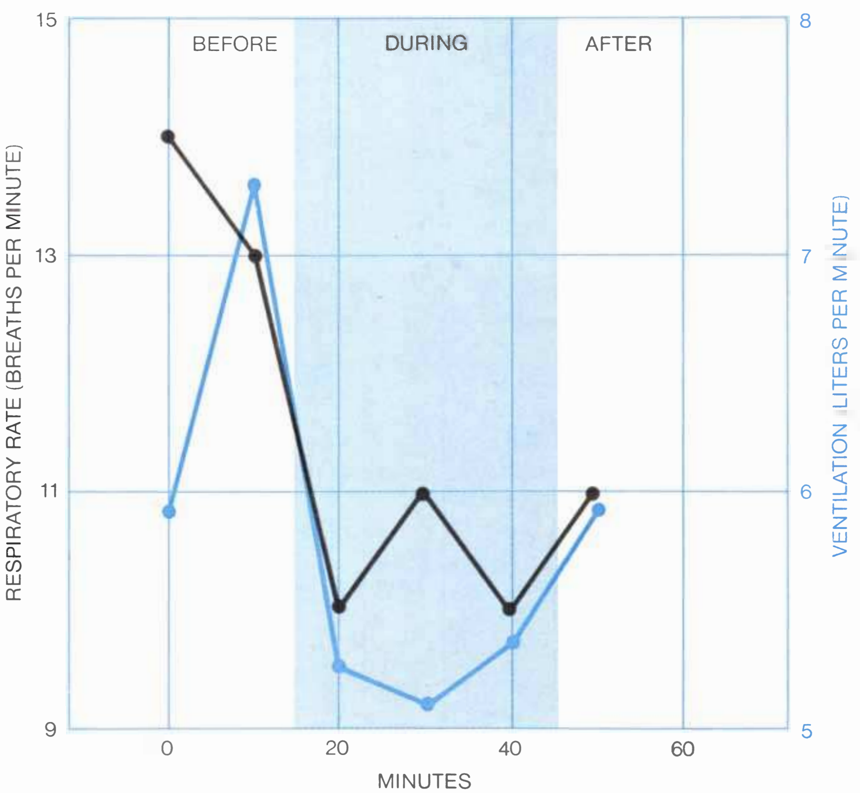
To sum up, our subjects during the practice of transcendental meditation manifested the physiological signs of what we describe as a "wakeful, hypometabolic" state: reductions in oxygen consumption, carbon dioxide elimination and the rate and volume of respiration; a slight increase in the acidity of the arterial blood; a marked decrease in the blood-lactate level; a slowing of the heartbeat; a considerable increase in skin resistance, and an electroencephalogram pattern of intensification of slow alpha waves with occasional theta-wave activity. These physiological modifications, in people who were practicing the easily learned technique of transcendental meditation, were very similar to those that have been observed in highly trained experts in yoga and in Zen monks who have had 15 to 20 years of experience in meditation.

How do the physiological changes during meditation compare with those in other relaxed states, such as sleep and hypnosis? There is little resemblance. Whereas oxygen consumption drops rapidly within the first five or 10 minutes of transcendental meditation, hypnosis produces no noticeable change in this metabolic index, and during sleep the consumption of oxygen decreases appreciably only after several hours. During sleep the concentration of carbon dioxide in the blood increases significantly, indicating a reduction in respiration. There is a slight increase in the acidity of the blood; this is clearly due to the decrease in ventilation and not to a change in metabolism such as occurs during meditation. Skin resistance commonly increases during sleep, but the rate and amount of this increase are on a much smaller scale than they are in transcendental meditation. The electroencephalogram patterns characteristic of sleep are different; they consist predominantly of high-voltage (strong) activity of slow waves at 12 to 14 cycles per second and a mixture of weaker waves at various frequencies—a pattern that does not occur during transcendental meditation. The patterns during hypnosis have no relation to those of the meditative state; in a hypnotized subject the brain-wave activity takes the form characteristic of the mental state that has been suggested to the subject. The same is true of changes in heart rate, blood pressure, skin resistance and respiration; all these visceral adjustments in a hypnotized person merely reflect the suggested state.

It is interesting to compare the effects obtained through meditation with those that can be established by means of operant conditioning. By such conditioning



INCREASE IN INTENSITY of "slow" alpha waves, at eight to nine cycles per second, was evident during meditation (*colored area*) in electroencephalograph readings of the subjects' frontal and central brain regions. This is a representative subject's frontal reading. Before meditation most subjects' frontal readings showed alpha waves of lower intensity.



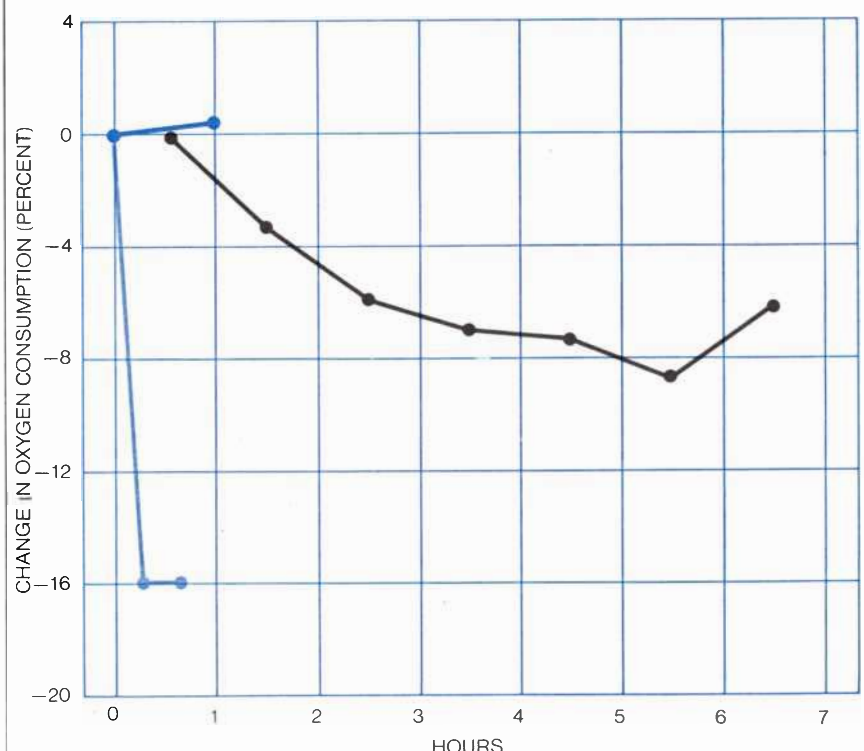
DECREASES OCCURRED in respiratory rate (*black*) and in volume of air breathed (*color*) during meditation. The ratio between carbon dioxide expired and oxygen consumed, however, continued unchanged and in the normal range during the entire test period.

animals and people have been trained to increase or decrease their heart rate, blood pressure, urine formation and certain other autonomic functions [see "Learning in the Autonomic Nervous System," by Leo V. DiCara; SCIENTIFIC AMERICAN, January, 1970]. Through the use of rewards that act as reinforcers a subject is taught to make a specific visceral response to a given stimulus. This procedure and the result are quite different, however, from what occurs in transcendental meditation. Whereas operant conditioning is limited to producing specific responses and depends on a stimulus and feedback of a reinforcer, meditation is independent of such assistance and produces not a single specific response but a complex of responses that marks a highly relaxed state.

The pattern of changes suggests that meditation generates an integrated response, or reflex, that is mediated by the central nervous system. A well-known reflex of such a nature was described many years ago by the noted Harvard physiologist Walter B. Cannon; it is called the "fight or flight" or "defense alarm" reaction. The aroused sympathetic nervous system mobilizes a set of physiological responses marked by increases in the blood pressure, heart rate, blood flow to the muscles and oxygen consumption. The hypometabolic state produced by meditation is of course opposite to this in almost all respects. It looks very much like a counterpart of the fight-or-flight reaction.

During man's early history the defense-alarm reaction may well have had high survival value and thus have become strongly established in his genetic makeup. It continues to be aroused in all its visceral aspects when the individual feels threatened. Yet in the environment of our time the reaction is often an anachronism. Although the defense-alarm reaction is generally no longer appropriate, the visceral response is evoked with considerable frequency by the rapid and unsettling changes that are buffeting modern society. There is good reason to believe the changing environment's incessant stimulations of the sympathetic nervous system are largely responsible for the high incidence of hypertension and similar serious diseases that are prevalent in our society.

In these circumstances the hypometabolic state, representing quiescence rather than hyperactivation of the sympathetic nervous system, may indicate a guidepost to better health. It should be well worthwhile to investigate the possibilities for clinical application of this state of wakeful rest and relaxation.



CONSUMPTION OF OXYGEN is compared in three different circumstances: during hypnosis (*color*), sleep (*black*) and meditation (*light color*). No significant change occurs under hypnosis. One study shows that oxygen consumption is reduced by about 8 percent after five hours' sleep. Meditation brings twice the reduction in a fraction of the time.